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HABITAT D'ALIMENTATION ET DE DÉPLACEMENT DES CHAUVES-SOURIS LE LONG D'UN GRADIENT DE PAYSAGES DU SUD DU QUÉBEC

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RÉSUMÉ

Comme pour plusieurs autres espèces animales, le déclin des populations de chauves-souris est documenté un peu partout sur la planète. Au Québec, quatre espèces se retrouvent sur la liste des espèces susceptibles d'être désignées menacées ou vulnérables. Plusieurs raisons, dont la dégradation des habitats, sont mises en cause. Toutefois, le manque de connaissances sur l'utilisation de l'habitat par chacune des espèces de chauves-souris retarde l'élaboration et l'application de mesures de protection. Au Québec, aucune étude n'avait été faite sur la distribution de l'activité nocturne des chauves-souris. Bien que plusieurs recherches aient été effectuées, au cours des années, sur les relations entre les chauves-souris et leur habitat, peu d'entre elles se sont intéressées à la distribution des différentes espèces de chauves-souris en présence de plusieurs éléments de l'habitat. De plus, dans la plupart des études, l'analyse ne se fait qu'à une échelle spatiale donnée. La mise en place au Québec d'un réseau d'inventaires acoustiques de chauves-souris favorise dorénavant la caractérisation des habitats d'alimentation et de déplacement des chauves-souris, au Québec. L'objectif principal du projet visait la caractérisation des habitats d'alimentation et de déplacement des chauves-souris au Québec. Les objectifs de cette étude étaient (1) de déterminer les différences dans l'utilisation nocturne de l'habitat par les chauves-souris en fonction d'un gradient allant d'un paysage urbanisé, d'un paysage agricole, et enfin d'un paysage forestier, retrouvé à travers les trois régions étudiées, (2) de définir les caractéristiques d'habitat d'alimentation et de déplacement utilisées par chaque espèce de chauve-souris, et finalement (3) de montrer comment les variables d'habitat explicatives varient lorsque différentes échelles spatiales sont utilisées.

Dans les trois régions choisies, des bénévoles du réseau ont enregistré et localisé à l'aide de GPS les cris de chauves-souris le long de parcours routiers de 20 km. Ces informations ont été transférées sur système d'information géographique. Plusieurs variables d'habitat ont été obtenues à partir de cartes topographiques informatisées et d'orthophotos afin de permettre l'analyse des relations chauves-souris/habitat à l'aide de régressions logistiques multiples. Des tests de Wilcoxon (« signed rank ») ont servi à vérifier les similitudes dans la distribution inter-annuelle des chauves-souris. Les analyses ont été répétées à plusieurs échelles spatiales. Les résultats montrent que les *Myotis* sont abondantes en milieu agricole (45 % des cris) et en milieu forestier (68 %), mais presque absentes du milieu urbain (0,5%). En milieu urbain, la grande chauve-souris brune est l'espèce la plus commune (58 %). Les tests ont montré que, souvent, il n'y a pas de différences significatives dans le positionnement des chauves-souris le long des circuits, année après année. Parmi les variables d'habitat qui ont influencé le plus la présence de chauves-souris, les différents types de bâtiments et les lampadaires blancs semblaient les plus importantes. La présence de ruisseau en paysage agricole est également associée à la présence des chauves-souris. Les variables d'habitats expliquant l'occurrence de chauves-souris varient dépendant de l'échelle spatiale, de l'espèce et du paysage.

MOTS-CLÉS : chauves-souris, habitat, urbain, rural, forestier

INTRODUCTION GÉNÉRALE

Le déclin de plusieurs populations de chauves-souris a été constaté un peu partout à travers la planète, même chez des espèces largement distribuées (Pierson 1998). En Amérique du Nord, plusieurs espèces sont maintenant considérées comme étant menacées ou vulnérables dans différents états ou provinces (Pierson 1998). Au Québec, quatre espèces de chauves-souris sont inscrites sur la liste des espèces susceptibles d'être désignées menacées ou vulnérables (Beaulieu 1992). Dans la majorité des cas, les pressions humaines seraient à la source de la diminution de la diversité et de l'abondance des chauves-souris. La perte d'habitat, la fermeture d'accès aux mines, le dérangement dans les sites d'hibernation et les coupes de forêts matures seraient des facteurs qui affectent considérablement les populations de chauves-souris (Altringham 1998). Les chauves-souris ont un faible taux de reproduction ce qui engendre un faible taux de croissance de la population. Ces caractéristiques limitent la capacité de la population à se rétablir lorsqu'elle est décimée. Les chauves-souris sont donc particulièrement vulnérables à la dégradation des habitats (Racey et Entwistle 2003). Pourtant, le manque de connaissances au niveau des relations entre les chauves-souris et leur habitat est évident (Fenton 1997, Miller et al. 2003). Une meilleure compréhension des besoins en matière d'habitat constitue une étape essentielle à la conservation des chauves-souris (Fenton 1997, Arnett 2003, Racey et Entwistle 2003).

Pourtant, en territoire québécois, aucune étude n'a été entreprise sur les relations entre les chauves-souris et leur habitat. De ce fait, il est pratiquement impossible d'instaurer des mécanismes de gestion des habitats pour préserver les populations de chauves-souris. Dans un tel contexte, il est primordial de mieux comprendre la relation entre les caractéristiques d'habitat et la présence de chauves-souris.

Parmi les différents aspects de leur écologie, la présence d'abris diurnes et de sites d'alimentation de qualité influencent largement la distribution de l'activité des chauves-souris (Kunz 1982a, Fenton 1990). D'une part, les abris diurnes sont une ressource importante pour les chauves-souris puisqu'elles y passent la majeure partie de leur temps (Kunz 1982a). Cet aspect de l'écologie des chiroptères a reçu beaucoup d'attention et les structures requises pour le repos et la maternité des chauves-souris sont, dans l'ensemble, bien décrites. De façon générale, les chauves-souris présentes en milieu tempéré trouvent un abri diurne dans les peuplements forestiers allant de matures à surannés, dans les cavités ou sous l'écorce des arbres hauts à couronne large et légèrement dépéris (Vonhof et Barclay 1996, Foster et Kurta 1999). Certaines espèces trouveront refuge dans les constructions humaines (Kunz 1982a). La caractérisation des abris diurnes a déjà permis, à certains endroits, d'élaborer des politiques pour leur conservation (Walsh et Harris 1996).

Toutefois, les chauves-souris passent une grande partie de la nuit en quête de nourriture. La caractérisation des sites d'alimentation est complexe et moins bien documentée. Leur spécification est pourtant essentielle au processus de conservation. Une mosaïque d'habitats est habituellement utilisée, par chacune des espèces, pour les activités nocturnes, comme l'alimentation et le déplacement (Fenton 1997). Ces activités peuvent être réparties sur un grand territoire (Fenton 1997). Une chauve-souris peut parcourir plusieurs kilomètres pendant une nuit pour se nourrir (Brigham 1991, Pierson 1998). Toutefois, même si le territoire qu'elles utilisent peut être très vaste, les chauves-souris ne s'alimentent pas de manière uniforme autour de leur abri diurne mais concentrent plutôt leur chasse dans des petits secteurs préférentiels. Walsh et Harris (1996) ont constaté que les habitats préférentiels utilisés, lors des activités nocturnes, par l'ensemble de la communauté de chauves-souris représentaient 1% à 4% des habitats disponibles. Plusieurs études montrent que les chauves-souris se nourrissent à des endroits bien définis. Plusieurs ont observé (Kunz 1973, Brigham 1991, Hickey et Fenton 1996) que certains individus revenaient nuit après nuit à un site spécifique pour s'alimenter, et parfois sur plusieurs années. Brigham et Fenton (1986) ont observé que les chauves-souris restaient fidèles à leurs sites d'alimentation même après que leur abri diurne eut été condamné. Toutes ces observations tendent à montrer que les chauves-souris recherchent des sites d'alimentation possédant des caractéristiques définies.

Différents travaux ont montré que certaines structures d'habitat étaient davantage utilisées par les chauves-souris que d'autres lors de leurs activités nocturnes. Par exemple, il a été observé que l'abondance de certaines espèces étaient plus grande dans les milieux riverains que les milieux non-riverain (Grindal, Morissette et Brigham 1999, Holloway et Barclay 2000), dans les forêts très matures par rapport aux jeunes forêts (Humes et al. 1999, Crampton et Barclay 1998; Jung et al. 1999), dans les forêts aménagées versus les forêts intactes (Grindal et Brigham 1998, Humes et al. 1999) et dans les habitats linéaires (ex. les haies d'arbustes ou les haies brise-vent) versus les milieux ouverts (Limpens et Kaptteyn 1991, Verboom et Spoelstra 1999). Bien que ces études fassent ressortir l'influence de certains habitats sur la présence de chauves-souris, elles ne permettent pas de dresser un portrait plus intégré des besoins des chauves-souris quant à l'importance relative de chacun de ces habitats à l'échelle du paysage. Les résultats de ces observations peuvent difficilement être appliquées à l'échelle d'un paysage mais seulement à celle des habitats définis.

Au cours des dernières années, seulement quelques chercheurs ont travaillé à analyser la distribution des chauves-souris dans le paysage à l'aide de modèles complexes qui incluent plusieurs variables d'habitat. La mobilité des chauves-souris, leur mode de vie nocturne et les difficultés reliées à leur identification en font un des groupes d'animaux les plus difficiles à étudier et les études à grande échelle sont complexes (Walsh et Harris 1996). L'arrivée de technologies telles que les systèmes d'information géographique (GIS) et les systèmes de positionnement global (GPS) permettent, dorénavant, un avancement dans ce domaine en facilitant l'analyse des caractéristiques d'habitat et le positionnement des données dans l'espace.

Au Québec, depuis 2001, un réseau d'inventaires acoustiques de chauves-souris a été mis sur pied afin de documenter la présence de chauves-souris sur l'ensemble du territoire québécois. Le réseau québécois d'inventaires acoustiques des chauves-souris récolte des données sur la distribution des différentes espèces de chauves-souris lors de leurs activités nocturnes, soit l'alimentation et le déplacement. Comme la position des chauves-souris détectées le long des circuits d'écoute est géoréférencée, ce réseau offre une base de donnée intéressante pour analyser les caractéristiques d'habitat de leurs sites d'alimentation et de déplacement.

Pour accroître les connaissances sur les relations chauves-souris/habitat, et en nous basant sur le réseau d'inventaires, nous avons entrepris une étude qui avait pour objectif principal la caractérisation des habitats d'alimentation et de déplacement des chauves-souris au Québec. Les objectifs de cette étude étaient, en premier lieu, de déterminer les différences dans l'utilisation nocturne de l'habitat par les chauves-souris en fonction d'un gradient allant d'un paysage urbanisé, d'un paysage agricole, et enfin, d'un paysage forestier retrouvé à travers les trois régions étudiées. De plus, l'étude avait pour but de définir les caractéristiques d'habitat d'alimentation et de déplacement utilisées par chaque espèce de chauve-souris. Finalement, nous voulions observer comment les éléments d'habitat agissent sur l'occurrence à différentes échelles spatiale.

BAT-HABITAT RELATIONSHIPS ALONG A GRADIENT OF LANDSCAPES, IN SOUTHERN QUÉBEC, CANADA

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ABSTRACT

In Quebec (Canada), four of eight bat species have been listed as potentially threatened or vulnerable. However, few studies have addressed bat use of habitat in this part of their distribution range. A network of bat monitoring routes (each 20 km long) in which trained volunteers have gathered data using ultrasonic detectors has been established since 2000. We used the data to assess species distribution in relation to habitat structures, during feeding and flight. We evaluated habitat use in three regions representing a gradient across urban (Laval), agricultural (Eastern Townships) and mostly forested (Mauricie) landscapes. We found that *Myotis* species are abundant in the agricultural landscape (45% of all calls) and the forested landscape (68%), but virtually absent in the urban setting of Laval (0.5%). In Laval, big brown bats are most common (58%). There were often no significant differences in the abundance of bats along the monitoring routes from year to year. We used three sizes of buffer zones for analyses (50 m, 100 m and 200 m diameter) along monitoring routes. In Mauricie (largely forested), there was a positive relationship between the occurrence of *Myotis* species and big brown bats and the presence of white (mercury vapour) streetlamps (200 m diameter buffer zones). White streetlamps also had a positive effect on *Myotis* species occurrence in the agricultural landscape. In the same region, bridges positively influenced the occurrence of *Myotis* species and hoary bats (100 m diameter buffer zones). In the urban region, big brown bat, silver bat and hoary bat presence was negatively related to the abundance of structures such as roads, houses and large buildings, but the influence of each variable changes depending on the scale of analysis. Overall, we found that some specific habitat structures affect bat activity positively or negatively, while others have no significant effect. Many relationships are not detectable at all spatial scales, but only at a specific scale.

INTRODUCTION

The populations of many bats are declining throughout the world, even in widely distributed species (Pierson 1998). In Quebec (Canada), four out of the eight species occurring in the province are listed as potentially threatened or vulnerable (Beaulieu 1992). Bats have a relatively low reproductive rate, which generates a low population growth rate. Those characteristics limit the capacity of bat populations to recover from disturbance. Therefore, bats are particularly vulnerable to habitat destruction or deterioration (Racey and Entwistle 2003). Yet, there is a lack of knowledge about the relationships between bats and their habitat (Fenton 1997, Miller et al. 2003). This situation is an obstacle in defining specific actions to take in order to preserve bat populations (Fenton 1997, Arnett 2003, Racey and Entwistle 2003).

The presence of suitable day roosts and nocturnal foraging habitat largely influences the distribution of bat activity (Kunz 1982, Fenton 1990). Day roosts are an important resource for bats because they spend most of their time in those structures (Kunz 1982 a). This aspect of bat ecology has received considerable of attention and the appropriate structures required for rest and reproduction of many bat species are well-described. Roost site characterizations have been used to establish policies for bat conservation in some regions (Walsh and Harris 1996). However, bats spend most of the night foraging. Characterizing feeding sites is much more complex and has received far less attention. Individual bats use a mosaic of habitat elements during nocturnal activity (Fenton 1997). These activities are spread over large areas (Fenton 1997). A bat can travel several kilometres in a single night in order to feed (Brigham 1991, Pierson 1998). Even thought they use large home range, bats do not feed uniformly over these areas, but rather concentrate hunting in preferred sectors. Walsh and Harris (1996) reported that preferred feeding habitats represented only 1% to 4% of available habitats used by a bat population during nocturnal activities.

Some studies have shown that individuals repeatedly return to a specific site to feed (Kunz 1973, Brigham 1991, Hickey and Fenton 1996), in some cases regularly over many years. Brigham and Fenton (1986) observed that bats were faithful to a feeding site even after they were evicted from their roost. All of these observations support the hypothesis that bats seek feeding sites with specific characteristics.

Several authors have shown that bats used certain habitat structures more often than others during nocturnal activities. For instance, the abundance of certain bats is greater in riparian habitats than in non-riparian habitats (Grindal, Morissette and Brigham 1999, Holloway and Barclay 2000), in over-mature forests than in young forests (Humes et al. 1999, Crampton and Barclay 1998, Jung et al. 1999), in managed forests relative to intact forests (Grindal and Brigham 1998, Humes et al. 1999), and in linear habitats (i.e tree rows and hedgerows) versus open habitats (Limpens and Kapteyn 1991, Verboom and Spoelstra 1999). However, there is little quantitative information available about the relationships between the distribution of the nocturnal activities of bats and multiple landscape characteristics. No study has been conducted on the subject in southern Quebec. It would be beneficial to acquire such knowledge since it is a region where species diversity is high but which is also submitted to high human pressure.

The purpose of this study was to improve our knowledge of bat-habitat relationships by characterizing the feeding and commuting habitats of bats in southern Quebec. We studied areas representing an urban landscape, an agricultural landscape and a mostly forested landscape to create a gradient of decreasing human-made structures and natural habitat loss and modification. Some bat species are well adapted to urban settings and have benefited from man-made structures, whereas other species decline and are associated with more natural landscapes (Pierson 1998). The objectives were to determine if differences in bat species habitat use exist along a gradient of urban to forested landscapes, and to identify habitat structures used by bat species during nocturnal feeding and commuting activities. We hypothesized that some habitat elements would influence differently bat presence depending in which landscape they are found. Patterns and relationships of all habitat elements vary in between landscapes and this could influence their effect on bat presence. It is expected that forested areas are important to many bats species, especially in urban landscapes where those habitats offer roosting opportunities and a source of insects. A third objective is to determine if bat-habitat relationships are expressed differently when using different spatial scales in the analysis.

MATERIAL AND METHODS

Study area

This study was carried out within the network of acoustical bat inventories of Quebec, Canada. Sampling methods apply generally to the whole network. This monitoring network was initiated in 2000 with the Laval route and in 2004 grew to a province wide, which includes 15 routes. The goal of the network is to allow repeatable long term monitoring of bats, in order to detect trends in abundance and distribution. Three regions with different landscapes were chosen for sampling to provide a general overview of bat-habitat relationships in southern Quebec; Laval, Eastern Townships and Mauricie, which represent different types of landscapes that offer contrasting habitat characteristics (Fig. 1; Table 1). Laval (45°,15' N, 73˚,73' W) is characterize by urbanized landscapes. It includes a large percentage of built-up areas, a small forest area and numerous isolated trees. The Mauricie region (46,62' N, 72˚, 73' W) is a forested landscape. Woodland covers a large percentage of the area. The sampling route of this region also partly borders a lake and crosses a section of agricultural fields. The third route is located near the village of Way's Mill (45˚,15' N, 72˚,02' W) in the Eastern Townships. It traverses mainly agricultural landscapes, where small woodlots are abundant and water bodies rare.

Sampling of echolocation calls

The network of bat acoustic inventories biologists defined census methods used for the project and determined the sampling design but the field sampling was done by trained volunteers. In each region, a team of at least two volunteers inventoried a unique route. The route, which usually forms a loop, covers a distance of 20 km and traverses habitats representative of the region. Inventory sessions were conducted between June 15th and July 30th each year. Teams completed a minimum of 90 minutes of recording during this period. Sessions began 15 minutes after sunset, the time at which bats begin their nocturnal activities (Kunz 1973, Brigham and Fenton 1986). Sampling was carried out from a slowly moving vehicle

(20km/h). Bat calls were recorded using an Anabat II bat detector (Titley Electronics, Australia) coupled to a tape recorder. The detector was maintained outside the vehicle at an angle of 45° in order to detect bats. When a bat was heard, the vehicle was stopped and a volunteer recorded calls for one minute. Position was determined using a GPS. The data were collected from 2000 to 2003 (4 years) for the Laval region, but only in 2002 and 2003 (2 years) for the Mauricie and the Eastern Townships regions.

Recorded calls were coded and transferred on computer using the Anabat II ZCA interface module. Sonograms were produced by sound analysis software (*Anabat 5, version 5.7*). The firm Envirotel 3000 identified species from recorded calls. In most cases, bats were identified to species. It was impossible to differentiate little brown bats (*Myotis lucifugus*) from northern long-eared bats (*Myotis septentrionalis*). Small-footed bats (*Myotis leibii*) are not identified since local reference call for this species are not available. All these species were combined as *Myotis*. The number of bat passes was also estimated (where a segment of 15 seconds of identifiable calls equals a pass).

<u>Habitat characteristics</u>

The routes inventoried were integrated into (1:20 000) geographical information system (Arcview 3.1, Environmental Science Research Institute). Circular buffer zones were edited along the routes, at a regular distance to acquire habitat variables to which bat presence could be related (Fig. 2). We used three sizes of buffer zones in order to analyze bat-habitat relationships at several spatial scales. As an example, for the smallest scale, on a route of 20 km long we created buffer zones of 50 m diameter, located at every 50 m along the route for a total of 400 buffer zones. The topographic maps allowed us to obtain habitat variables for each region surrounding the sampling routes. From those maps, three types of buildings were distinguished; houses and other small buildings (recorded as a point in the GIS), small commercial buildings or barns (recorded as a line in the GIS) and large buildings such as hospitals, shopping malls, offices, factories or apartment buildings (recorded as an area in the GIS). Other variables obtained from topographic maps included roads, bridges, forested areas, open areas, streams and other water bodies. Some variables, which seemed appropriate to include, were not available from the topographic maps. Streetlamps were surveyed and their position was recorded by GPS. The type of the streetlight, either white for mercury vapour lamps or yellow for non-mercury vapour lamps, was also recorded. Additionally, the presence of windbreaks or tree rows and isolated trees was acquired from digitalized aerial photographs (orthophotos) and incorporated into our computerized topographic maps. A total of 13 habitat variables were taken into account for this study (Table 1). Variables from the digital maps were originally points, lines or areas. Average areas were determined for point structures (houses, streetlights) and areas of linear structures (streams, bridges, linear buildings, roads) were determined using average widths. The total area of every habitat variable was measured and their percentage of coverage of each buffer zone calculated in order to facilitate comparisons and analyses. In addition to the 50 m diameter buffer zones, analyses were repeated for 100 m and 200 m diameter buffer zones. Scales were selected in order so that chosen habitat characteristics would influence bat presence more directly. Some variables such as streetlights and isolated trees could not reasonably be related to detected bat presence at larger scales.

Statistical analyses

A first statistical test was used to compare the distribution of bat calls along each route from year to year. An indication that bats are found in the same place between years would suggest that they use particular habitat. To do so, we used Wilcoxon signed rank test to evaluate the similarity of bat calls distribution between years. That particular test evaluates if the difference between the abundance of all bat passes recorded in each buffer zone is significantly different from zero (0). A significant result would indicate that bats were not located in the same buffer zones.

We used multiple logistic regressions to test the relationships between habitat characteristics and the probability of occurrence for each bat species in each region. Bat presence or absence inside a buffer zone was linked to habitat characteristics within that buffer zone. Analyses were repeated for each species, in each region and for all of the three spatial scales (buffers of 50 m, 100 m and 200 m diameter). A log-likelihood test allowed us to evaluate the statistical significance of variable input in the model. Odds ratio values indicated the influence of each variable of the model on the probability of occurrence of a species. In our particular case, the odds ratio value is the log of the probability of a species being absent over the probability of it being present. An odds ratio value that is an entire value implies that the probability of a species being present is decreased as the area of the habitat variable is increased. On the other hand, an odds ratio value that is a fraction implies that the probability of a species being present increases as the habitat variable surface area is increased.

Since we tested three scales, we wanted to have an idea of which one would be more appropriated to use if further studies were conducted through the network of acoustic bat inventories. Akaïke's Information Criterion (AIC) was used to categorize the "best" model for each species and region when looking at scale. Second-order criterion (AIC_c) was used when sample size was small (i.e., $n/K < 40$, where K = numbers of variables + the intercept). Models compared were those selected by multiple logistic regressions in the previous step.

RESULTS

Species composition

A total of 54 sampling nights were conducted in the three regions, resulting in 986 bat passes recordings. An additional 93 passes were detected but were not recorded. The species recorded, in order of abundance were: *Myotis* (305 passes), *Eptesicus fuscus* (Big brown bat; 361 passes), *Lasiurus cinereus* (Hoary bat; 177 passes), *Lasionetyris noctivagans* (Silver-haired bat; 59 passes) and *Lasiurus borealis* (Red bat; 1 pass). Other bat passes were also recorded but their species identification was not possible (93 passes).

Species composition varied between regions (Fig. 3). In the urban landscape, *E. fuscus* was the most common species (57.6 % of detected calls), while its presence was less frequent in other regions (less than 6 % of detected calls). Inversely, *Myotis* species were common in the agricultural landscape (45.1 % of detected calls), as well as in the forested landscape (68.3 % of detected calls), but were virtualy absent from the urban landscape (< 1 % of detected calls). *L. cinereus* was relatively abundant in all regions. Recordings of *L. noctivagans* represented almost 9 % of detected calls in the urban landscape.

Inter-annual comparison of the location of detections along sampling routes

Analysis with the Wilcoxon signed rank test indicates that the location of bat passes in the urban landscape was similar in 2000 and 2001, in 2001 and 2003 and, at a spatial scale of 200 m only, in 2000 and 2003 (Table 2). In the agricultural region, distribution of bat pass locations in 2002 and 2003 was not significantly different (Table 2). Bat pass locations in the forested landscape (Mauricie) differed significantly between 2002 and 2003 (Table 2).

Habitat variables

Urban landscape

In Laval, buildings and roads had a negative effect on the occurrence of species such as *E. fuscus*, *L. cinereus* and *L. noctivagans*. For the 50 m diameter buffer zone analysis, the probability of occurrence of *E. fuscus* decreased when the quantity of roads (Log-Likelihood Ratio Chi^2 = 7.38, $p < 0.01$, Odds Ratio = 25.19) and buildings increased (small buildings LR Chi^2 = 4.98, p = 0.03, O.R. = 4.88; linear buildings LR Chi^2 = 10.03, p <0.01, O.R. = 164.20 or large buildings LR Chi^2 = 7.75, $p < 0.01$, O.R. = 25.55, Table 3). These variables had the same effect on *E. fuscus* and *L. noctivagans* at the 100 m analysis scale (Table 4). Also at the 100 m diameter buffer zone scale, roads (LR Chi^2 = 13.65, p < 0,001, O.R. =336.57,) and large buildings negatively influenced *L. cinereus* occurrence (LR Chi^2 = 8.69, p = 0.03, O.R. =99.11). At the larger scale (200 m buffer zone), two variables had a negative effect on the occurrence of bats. Linear buildings negatively influenced the occurrence of *E. fuscus* (LR Chi^2 = 9.35, p < 0.002, O.R. = 448.99) and *L. cinereus* (LR Chi^2 = 7.29, p = p < 0.01, O.R. = 1271.02), while large buildings negatively influenced *L. cinereus* (LR Chi^2 = 4.51, p = 0.03, O.R. = 34.01) and *L. noctyvagans* (LR Chi^2 = 8.18, p <0.01 O.R = 690.10; Table 5).

Forested landscape

In the Mauricie forested landscape, relationships between habitat variables and bat occurrence were significant at the 200 m scale. The occurrence of *E. fuscus* was more probable as the number of isolated trees (LR Chi^2 = 5.74, p = 0.02, O.R. < 0.0001) and white streetlamps increased (LR Chi^2 = 4.62, p = 0.03, O.R. <0.0001). Similarly, the occurrence of *Myotis* species was positively related to white streetlamp abundance (LR Chi^2 = 22.20, p < 0.001, O.R. = 0.0015; Table 5).

Agricultural landscape

In the Eastern Township agricultural region, white streetlamps were positively associated with *Myotis* occurrence. This relationship was significant at the 50 m (LR

Chi^2 = 5.74, p = 0.02, O.R = 0.0098) and 100 m scales (LR Chi^2 = 5.44, p = 0.02, O.R = 0.02) (Tables 3 and 4). At the 100 m scale, the presence of tree rows and bridges positively influenced bats. The presence of those features increased the probability of occurrence of *Myotis* species. (LR Chi^2 = 7.15, p < 0.01, O.R. = 00296 and LR Chi^2 = 8.29, p< 0.01, O.R. = 0.0026; Table 4). Bridges were also positively associated to the occurrence of *L. cinereus* (LR Chi^2 = 5.06, p = 0.02, O.R. < 0.0001). As for *E. fuscus*, its probability of occurrence increased with small buildings and forested areas at the 50 m scale (LR Chi^2 = 7.07, p < 0.01 and LR Chi^2 = 4.29, p = 0.04, O.R. = 0.0246; Table 3).

<u>*All regions combined*</u>

When we combined bat recordings of all regions, without regard to the type of landscape, relationships between habitat variables and bat occurrence were only visible at a scale of 200 m (Table 6). White streetlamps were always positively associated with the occurrence of bats (*E. fuscus, L. cinereus, L. noctyvagans* and *Myotis* spp.). Additionally, *E. fuscus*, *L. cinereus* and *L. noctivagans* were more likely to occur in the presence of isolated trees (Table 6). The probability of *E. fuscus* occurrence increased with presence of water bodies (LR Chi^2 = 5.33, p = 0.02, O.R. = 0.096). *L. cinereus* was positively linked with bridges (LR Chi^2 = 6.80, p < 0.01, O.R. = 0.0011,), but negatively with linear buildings (LR Chi^2 = 6.01, p = 0.01, O.R. = 150.64). Also, *Myotis* spp occurrence increased in the presence of tree rows (LR Chi^2 = 4.33, p = 0.04, O.R. = 0.1172) and forested habitats (LR Chi^2 = 5.93, p = 0.01O.R. = 0.2922), but decreased in the presence of large buildings (LR Chi^2 = 8.18, p < 0.01, O.R. = 26.50).

The first objective of using several spatial scales was to observe how variables varied in their influence on bat occurrence according to scale. The use of AICs allows for further distinctions between models at different scales. For all models compared, the 200 m scale (the largest) was always the most appropriate to describe bat/habitat relationships in different regions (Table 7).

DISCUSSION

Landscape use by bats

Species composition varied with landscape type. A major difference among landscapes was the abundance of *E. fuscus* in the urban habitat. This species was commonly detected to feed or commute in the urban landscape, but only occasionally encountered in the other two regions. Geggie and Fenton (1985) reported the opposite, in that foraging by *E. fuscus* were higher in rural areas than urban areas in Eastern Ontario and Western Quebec. However, other studies suggest that this species thrives in urban landscapes (Furlonger et al. 1987, Everette et al. 2001, Ghert and Chelsvig 2004). The fact that *E. fuscus* uses man-made structures as roosts (Kunz 1982a) can, to some extent, explain their abundance in urban landscapes. Similarly to *E. fuscus*, *M. lucifugus* also roosts in man-made structures (Fenton and Barclay 1980). Yet, *Myotis* species were virtually absent from the urban landscape. They were the most abundant species in the forested and agricultural landscapes. Vaughan *et al.* (1997) noted that *Myotis* were never found in villages in England. Insect density and diversity is often lower in urban landscapes (Faeth and Kane 1978, Geggie and Fenton 1985, Blair and Launer 1997). Our results could indicate that *Myotis* were not able to find suitable feeding areas or to exploit lower insect abundance in the urban landscape, whereas *E. fuscus* could. *M. lucifugus* are effective at feeding in patches of insects (Fenton and Barclay 1980), which may have been absent in the urban landscape. Another interpretation may be linked to the fact that *Myotis* distribution is sometimes restricted to areas near hibernacula. In fact, in a study by Furlonger et al. (1987) *Myotis* were most common in areas with potential hibernacula. This may be an explanation for the near absence of *Myotis* in the Laval region, but the presence of hibernacula has not been documented in any of the studied regions.

As for *L. noctivagans*, it was present in the urban landscape. Our study does not allow definition of its feeding habitat, but since it is known to roost in forested landscapes

(Kunz 1982 b, Vonhof 1995), we can assume that the presence of remnant woodlots, city parks or tree rows is important. This might also be the case for *L. cinereus,* another species commonly found in the urban landscape but which usually roosts in trees (van Zyll de Jong 1985, Willis and Brigham 2005). Interestingly, in our study, this species was present in all landscapes in the same proportion. This may indicate that this species is more tolerant to habitat modifications.

Habitat variables

There was a significant similarity in the distribution of bats from year to year in the urban and agricultural landscapes. This implies that there are particular sectors of the routes with specific habitat structure characteristics favouring the presence of bats. In many cases, it has been observed that some individual bats repeatedly return to a specific site to feed (Kunz 1973, Brigham 1991, Hickey and Fenton 1996), and sometimes year after year. Walsh and Harris (1996) reported that preferred habitats represented only 1% to 4% of available habitats used by a bat community during nocturnal activities. Even thought bats use large area during nocturnal activities, they do not feed uniformly but rather concentrate their hunting in preferred sectors.

Although a high abundance of bats was recorded in the urban landscape, they did not feed or commute in heavily developed areas where buildings and roads were abundant. Though *E. fuscus* can benefit from structures such as buildings for roosting purposes, as it was discussed earlier, those elements were associated with the absence of this species. This could imply that they do not feed close to their roosting sites. Everette *et al.* (2001) showed that big brown bats commuted greater distances than usually reported from their roosts in the urban core, in order to forage in refuges. Also, Duchamp, Sparks and Whitaker (2004) showed that the urban habitat was not important for foraging by *E. fuscus* although the species was found there roosting in man-made structures. Many have noticed that *E. fuscus* can commute to less favourable habitats to forage elsewhere (Geggie and Fenton 1985, Everette et al. 2001, Duchamp, Sparks and Whitaker 2004). In contrast, in the agricultural region, *E. fuscus* presence increased when small buildings were present. Geggie and Fenton (1985) also observed that *E. fuscus* often fed in the residential zones of rural areas. This can imply that habitat characteristics in the surroundings of those buildings corresponded to suitable feeding sites. In the agricultural region, small buildings were often old farmhouses located in a natural environment, which probably offers more feeding opportunities. It is interesting to note how a habitat element, small buildings for instance, can have different effects in different landscapes for a particular species. As mentioned earlier, small buildings were negatively associated with *E. fuscus* in the urban landscape, but positively associated with the same species in the agricultural landscape. Furthermore, no relationship was detected with this particular element in the forested landscape.

Of all habitat characteristics, the presence of white streetlights was the one that was the most often associated with bat presence. In the forested landscape, white streetlights were the elements that were most strongly associated to the presence of both *E. fuscus* and *Myotis*. White streetlights also positively influence *Myotis* in the agricultural region. Furthermore, for the data from all regions combined, white streetlights increased the probability of occurrence of *E.fuscus, L. cinereus, Myotis* spp. and *L. noctyvagans*. Bats are known to exploit insects under artificial lights (Furlonger et al. 1987, Rydell 1992, Rydell and Racey 1995, Hickey and Fenton 1996). Additionally, Svensson and Rydell (1998) found that white lights (mercury lamps) interfere with the defensive behaviours of some moths, which make them easier targets for bats. In Laval, streetlights had no effect on bats. Streetlights might have a lower power of concentrating local insects in the urban landscape since they are numerous and mostly located in highly developed areas.

Other important habitat characteristics strongly associated with the nocturnal activities of some species of bats included the presence of tree rows, isolated trees or forested areas. Isolated trees in the more agricultural part of the forested landscape route influenced positively the presence of *E. fuscus*. Moreover, data from all regions combined showed that the probability of occurrence of *E. fuscus*, *L. cinereus* and *L. noctivagans* was higher in the presence of isolated trees. As for *Myotis*, they were often recorded when tree rows were present in the agricultural landscape. Jaberg and Guisan (2001) concluded that hedges and isolated trees should be preserved in agricultural landscapes in order to improve the availability of bat foraging habitats. The value of scattered isolated trees as foraging habitats in rural land was also shown in Australia (Lumsden and Bennett 2005). Verboom and Spoelstra (1999) found that tree rows benefited bats because they offer protection from the wind and a food supply. Lewis (1970), proposed that insect density is higher near vertical landscapes features. When analyzing the ecology of different species of bats, many authors have shown the importance of woodlands as a structural element for increasing the presence of bats (e.g Walsh and Harris 1996, Vaughan, Jones and Harris 1997, Russ and Montgomery 2002). In this study, forested areas increased the presence of *E. fuscus* in the agricultural landscape, as well as of *Myotis* based on data from all regions combined. It was expected that forested areas would be more important to other bats species, especially in the agricultural and urban landscapes. However, our analyses failed to detect these relationships.

In the agricultural landscape, bridges were used by *Myotis* spp. *L. cinereus* were also active near bridges. It is known that open water is usually a good feeding habitat for many species and observations by many authors support this assertion (e.g. Grindal et al. 1999, Holloway and Barclay 2000, Russ and Montgomery 2002). Belwood and Fenton (1976) reported that insects emerging from water were a large part of the diet of *M. lucifugus*. Although water was present in the urban landscape, it was not associated with bat activity. Kurta and Teramino (1992) reported that rivers in city parks supported fewer bats than lakes in rural habitats. For a number of reasons (i.e. water pollution), aquatic insect communities are different in rural and urban streams (Jones and Clark, 1987). The large river adjacent to our urban study area (Des Prairies river) could be too turbulent to favour the presence of insects that are a useful food source to bats. Von Frenckell and Barclay 1987 showed that insects were less common over turbulent water. However, only actual insect sampling could verify this hypothesis. Prey may also be more difficult to detect due to the sound emitted by the turbulent water (Von Frenckell and Barclay 1987). As for bridges themselves, their importance during the nocturnal activities of bats may be due to their possible use as night roosts. Bats, especially *Myotis* species, sometimes use bridges as night roosts (Perlmeter 1995).

Effect of scale

The use of more than one spatial scale of bat-habitat relationship analyses allowed us to detect more habitat characteristics associated with bat presence. The three scales used were relatively similar in size, but the habitat elements associated with bat activity varied a lot from one to other. Many relationships would not have been detected if a single scale had been used.

This suggests that investigators should be careful when selecting a scale of analysis. Using larger scales than those used would not have been appropriate in this study due to the methods employed for sampling. Others have attempted to consider habitat selection by bats at different scales. Walsh and Harris (1996) did not observe differences in habitat use between local scale and large scale. Zimmerman and Glanz (2000) observed a difference in variables from one scale to another and concluded that management actions should be considered at multiple scales. However, Erikson and West (2003) detected no elements explaining bat activity at the landscape scale, while some variables did have an effect on bats at the stand scale. They suggested that studies should focus primarily on structural attributes of stands, features found at a smaller scales than the landscape.

Our study suggests that a 200 m scale is more appropriate. For all species that could be compared in a given region, the largest scale was the best. Bats exploit large areas of habitat since they can travel and feed at great speed. Habitat elements can influence bat presence, when they are chasing insects, even though they are detected several meters away. Statistical considerations may have influenced the AICs; since habitat variables came from less numerous buffer zones, the relationship with bat was stronger. Additionally, AICs favour models with less explicative variables. In our case, the models at 200 m scale always had low numbers of variables.

This study found differences in the relative importance of different landscapes for different bat species, as well as in the association of habitat structures with their nocturnal activities. The individual requirements of each species with respect to habitat characteristics varied from a landscape to another, and also at different spatial scales. These findings outline some of the elements that could be important when future bat habitat characterisations are undertaken. It is interesting to note that the urban landscape did support a considerable bat abundance and diversity. However, even if urban centres such as the Laval region seem to be good bat habitat, extensive urban development did not correspond to good foraging or commuting habitats. The Laval region may have sufficient suitable feeding habitat within it or nearby. Larger continuous and densely urbanized areas may be far less favourable to bats. Additionally, human-made elements such as buildings, roads, bridges, tree rows and streetlamps were generally strongly associated with the nocturnal activities of bats, either negatively or positively, in all types of landscapes. This indicates that it is of particular importance to carefully assess man-induced elements in a landscape when seeking to detect bat-habitat relationships.

Although improvements can be made in the measurement accuracy (of bat call detections in particular) and in the type of habitat variables measures (forest cover type, type of open areas, type of crops, etc.), the Quebec network of acoustical bat surveys has provided the first data for describing and studying bat-habitat relationships in this region. This network gathers important information on bat presence in various habitats of temperate regions. It also set basis for more adequate bat habitat management guidelines for the various types of landscape present in

Quebec, as well as in adjacent provinces and states with similar bat fauna, vegetation and land uses.

Other interesting avenues, which could complete the present study, include the localization of roosts and hibernacula. Those aspects of bat ecology can have an impact on the distribution of individuals in the landscape. By incorporating such data onto our maps, it would be possible to better understand the influence of roosting and hibernating sites on the feeding area.

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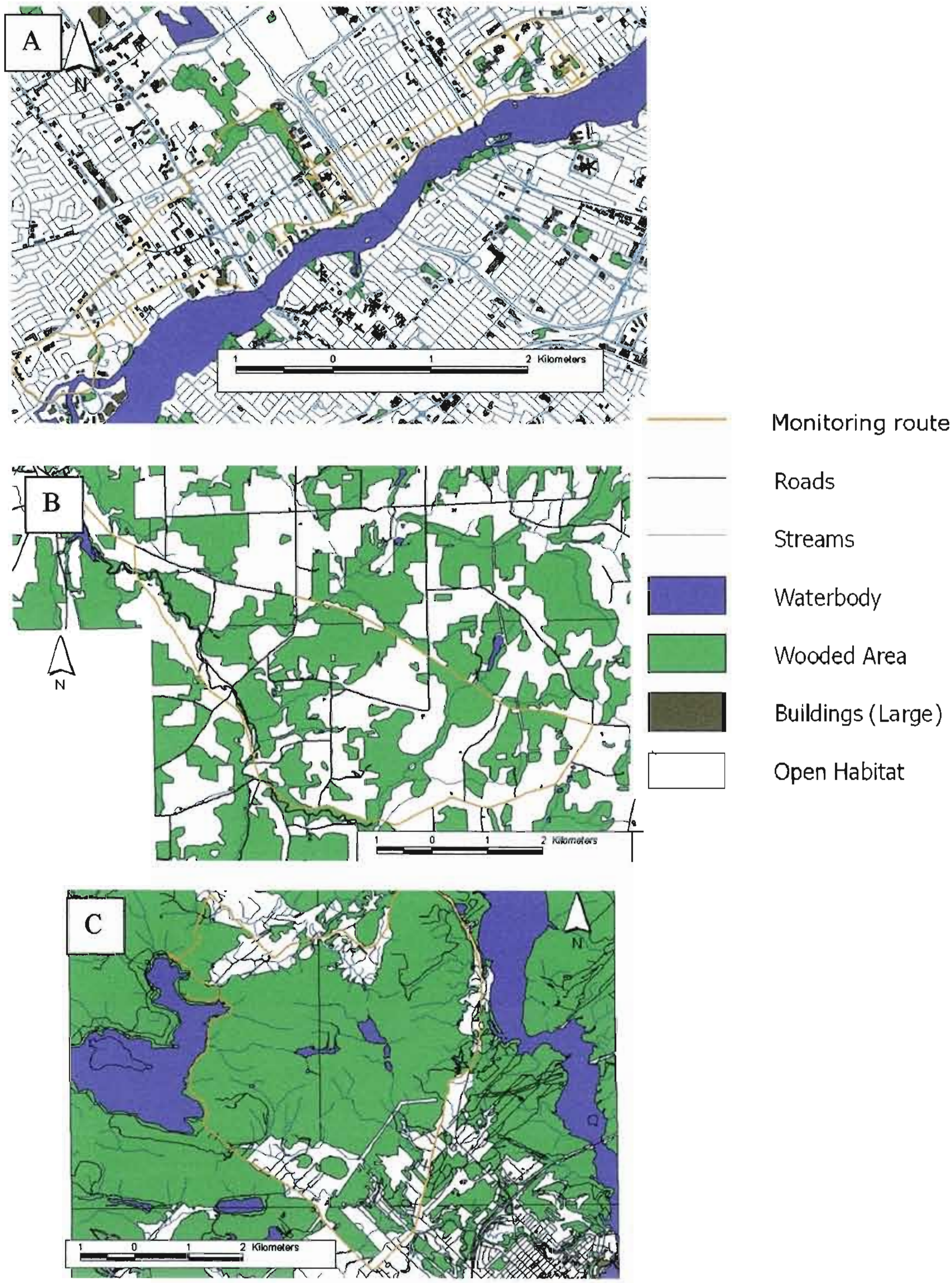

Figure 1 Maps of the three monitored routes showing cover type, roads and buildings; A) urban landscape (Laval); B) agricultural landscape (Eastern Townships); C) forested landscape (Mauricie)

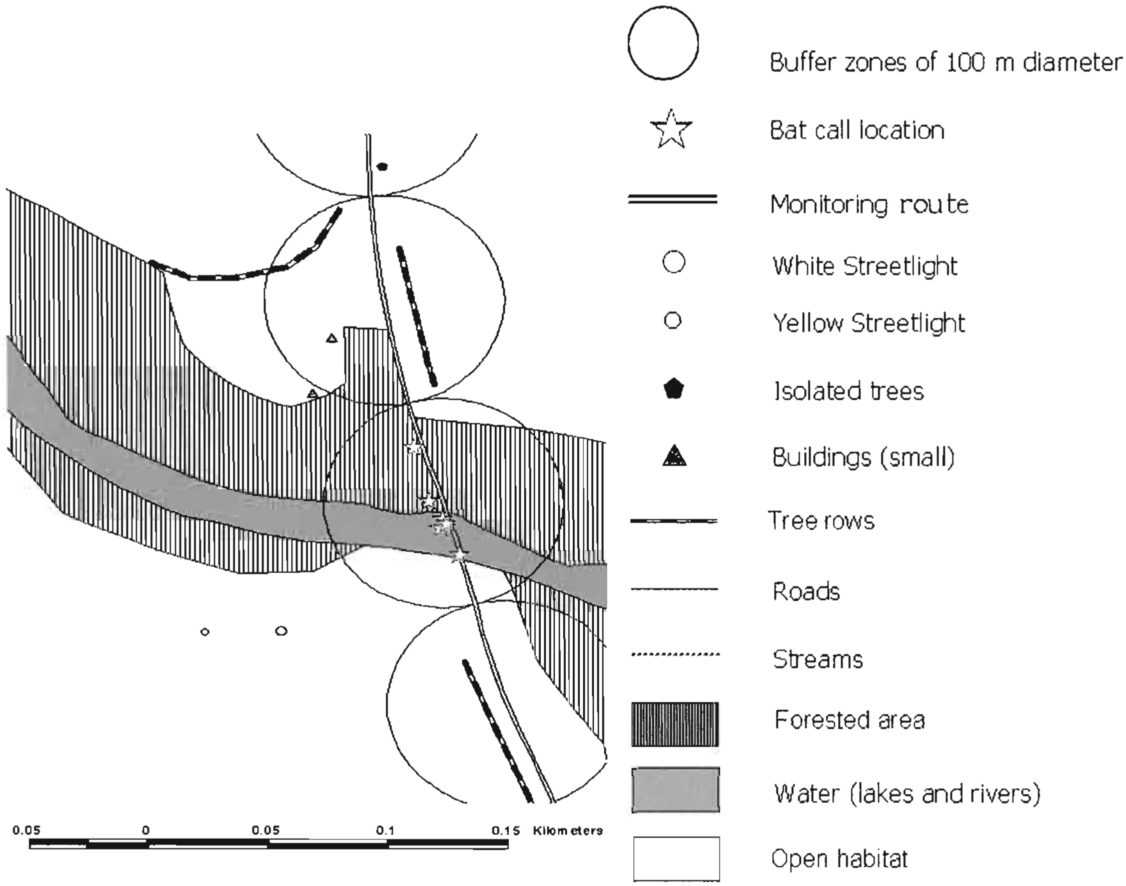

Figure 2 Close-up view of a route section and habitat analysis buffer area

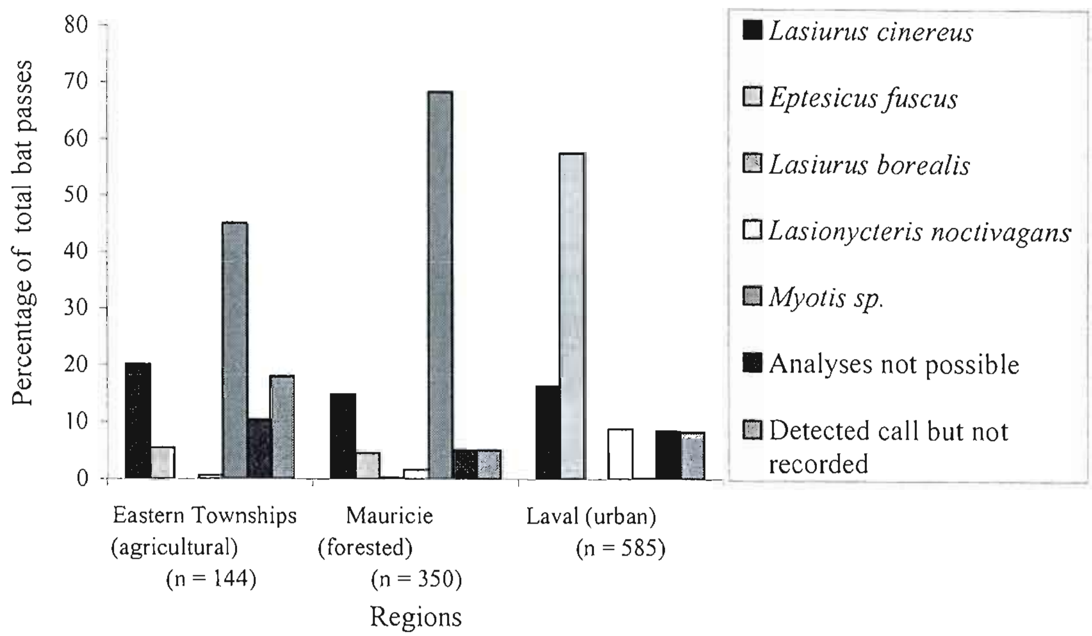

Figure 3 Total detections of bat species along monitoring routes in three regions

Table 1 Percentage of habitat variables included in the totality of habitat zones of 50 m diameter along each monitored route.

	Urban landscape (Laval)	Agricultural landscape (Eastern Townships)	Forested landscape (Mauricie)
Buildings (small)	0.72	0.04	0.23
Buildings (linear)	0.44	0.03	0.06
Building (large)	1.16	0.01	0.01
Water (streams)	0	0.21	1.24
Water (rivers and lakes)	0.72	0.51	0.21
Isolated trees	0.08	0.03	0
Tree rows	0.6	1.55	0.94
Forests	6.3	21.77	34.3
Open habitat	59.98	54.86	41
White streetlamps	0.01	0.01	0.01
Yellow streetlamps	0.01	0	0.01
Roads	29.43	20.78	21.99
Bridges	0.55	0.2	0

Table 2 Between year comparisons of the location of bat passes in three regions (t_{test} and Wilcoxon signed rank test).

	Laval												Eastern Townships		Mauricie	
	2000-2001		2000-2002		2000-2003		2001-2002		2001-2003		2002-2003		2002-2003		2002-2003	
	p>|t|	Signed-Rank	p>|t|	Signed-Rank	p>|t|	Signed-Rank	p>|t|	Signed-Rank	p>|t|	Signed-Rank	p>|t|	Signed-Rank	p>|t|	Signed-Rank	p>|t|	Signed-Rank
50 m	0.0345 *	0.053 *	<.0001	0.000	0.0167	0.001	<.0001	0.000	0.929 *	0.185 *	0.0365	0.001	0.314 *	0.144 *	<.0001	0.000
100 m	0.1936 *	0.251 *	0.0026	0.000	0.1682 *	0.045	0.0184	0.010	0.9048 *	0.435 *	0.0102	0.008	0.732 *	0.238 *	<.0001	0.000
200 m	0.2324 *	0.275 *	0.0034	0.001	0.2111 *	0.057 *	0.0184	0.010	0.9048 *	0.435 *	0.0102	0.008	0.443 *	0.387 *	<.0001	0.000

* Test value showing that bat passes location does not significantly differ between years tested.

Table 3 Regression analyses of bat occurrence over habitat variables in three different regions; using 50 m diameter habitat zones along monitoring routes.

Habitat variables (50 m diameter)	Laval (urban lanscape)				Mauricie (forested landscape)		Eastern Townships (agricultural landscape)			
	E. fuscus		*L. noctivagans*		*Myotis* spp.		*E. fuscus*		*Myotis* spp.	
	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio
Buildings (small)	0.03	4.88					< 0.01	< 0,0001		
Buildings (linear)	< 0.01	164.20								
Buildings (large)	< 0.01	25.55	0.02	< 0.0001						
Forested habitat					0.03	0.3669	0.04	0,0246		
White streetlamps					< 0.001	0.0929			0,02	0,0098
Yellow streetlamps					0.02	0.0781				
Roads	<0.01	25.19	0.02	45.63						
Model R^2	0.1226		0.0987		0.0825		0.4444		0.3646	

p_{value} from log likelihood ratio test; odds ratio values for log odds of absence of bats over presence

Table 4 Regression analyses of bat occurrence over habitat variables in three different regions; using 100 m diameter habitat zones along monitoring routes.

Habitat variables (100 m diameter)	Laval (urban lanscape)						Mauricie (forested landscape)		Eastern Townships (agricultural landscape)			
	E. fuscus		*L. cinereus*		*L. noctivagans*		*Myotis* spp.		*Myotis* spp.		*L. cinereus*	
	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio
Buildings(small)	0.03	4.85			< 0.01	26.30						
Buildings (linear)	< 0.01	162.63			< 0.01	> 1000	0.04	14904,54				
Buildings (large)	< 0.01	25.02	< 0.01	99.11	0.02	135.32						
Isolated trees											0.04	3,170e41
Tree rows									< 0.01	0.0296		
White streetlamps							< 0.01	0.0314	0.02	0.02		
Yellow streetlamps							0.01	0.0399				
Roads	< 0.01	26.39	< 0.001	336.57	0.01	111.01						
Bridges									< 0.01	0.0026	0,02	< 0,0001
Model R^2	0.1215		0.1564		0.2046		0.0978		0.3311		0.3532	

p_{value} from log likelihood ratio test; odds ratio values for log odds of absence of bats over presence

Table 5 Regression analyses of bat occurrence over habitat variables in three different regions; using 200 m diameter habitat zones along monitoring routes.

Habitat variables (200 m diameter)	Laval (urban lanscape)						Mauricie (forested landscape)				Eastern Townships (agricultural landscape)	
	E. fuscus		*L. cinereus*		*L. noctivagans*		*E. fuscus*		*Myotis* spp.		*Myotis* spp.	
	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio
Buildings (linear)	< 0.01	448.99	< 0.01	1271.02								
Buildings (large)			0.03	34.01	< 0.01	690.10						
Isolated trees							0.02	< 0.0001				
Bridges											< 0,01	0,0066
White streetlamps							0.03	< 0.0001	< 0.001	0,0015		
Model R^2	0.2038		0.1798		0.1873		0.6436		0.1932		0.2761	

p_{value} from log likelihood ratio test; odds ratio values for log odds of absence of bats over presence

Table 6 Regression analyses of bat occurrence over habitat variables in all regions combined; using 200 m diameter habitat zones along monitoring routes.

Habitat variables (200 m diameter)	All regions combined							
	E. fuscus		*L. cinereus*		*L. noctivagans*		*Myotis* spp.	
	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio	p_{value}	Odds ratio
Buildings (linear)			0.01	150.64				
Buildings (large)	0.02	0.0957					<0,01	26,50
Isolated trees	< 0.001	0.0487	0.01	0.1192	<0,01	0,0467		
Tree rows							0.04	0,1172
White streetlamps	<0.01	0.0258	< 0.001	0.0209	0,02	0,0309	< 0,001	0,0026
Forested habitat							0.01	0,2922
Bridges			<0.01	0.0011				
Water (rivers and lakes)	0.02	0.0957						
Model R^2	0.2091		0.1296		0.1599		0.1706	

p_{value} from log likelihood ratio test; odds ratio values for log odds of absence of bats over presence

Table 7 Comparison of models by spatial scale using AIC

	Laval						**Mauricie**		**Estrie**			
	E. fuscus		*L. noctivagans*		*L. cinereus*		*Myotis* sp.		*Myotis* sp.		*E. fuscus*	
	AIC	Delta AIC	AIC_c	Delta AIC_c	AIC	Delta AIC	AIC	Delta AIC	AIC_c	Delta AIC_c	AIC_c	Delta AIC_c
Spatial scale (50 m)	219,20	97,06	157,88	74,54			324,84	190,84	73,00	18,46	36,92	11,8
Spatial scale (100 m)	219,48	97,34	113,62	30,28	155,88	48,50	247,02	113,02	73,12	18,58		
Spatial scale (200 m)	122,14	0,00	83,34	0,00	107,38	0,00	134,00	0,00	54,54	0,00	25,12	0

CONCLUSION GÉNÉRALE

Dans l'ensemble, les résultats du projet répondent bien aux objectifs de départ. Premièrement, nous avons pu observer une différence dans la composition en espèces de chauves-souris entre les trois types de paysages. La composition en espèces du paysage urbain diffère largement de celle des paysages agricoles et forestiers. Cela constitue une première étape dans la connaissance des patrons de distribution des chauves-souris dans le sud du Québec. Du même coup, l'étude fournit des indications intéressantes sur l'importance des parcs urbains ou de végétation en général en milieu urbain, vu la présence significative d'espèces forestières dans la région de Laval. En second lieu, le projet a mis en évidence certaines variables d'habitat importantes lors de l'activité nocturne de plusieurs espèces de chauves-souris. Parmi les plus importantes, on retrouve les différents types de bâtiments, les lampadaires à lampes blanches, les ponts, ainsi que les arbres isolés et les rangées d'arbres. De plus, il est intéressant de noter que des éléments d'habitat, tels que les petits bâtiments et les lampadaires, peuvent avoir des effets positifs sur la présence d'une espèce dans une région donnée, négatifs dans une autre, et n'avoir aucun effet dans la troisième. En ce qui concerne le troisième objectif du projet, nous n'avons pas réussi à montrer comment la relation chauves-souris/habitat s'exprime à différentes échelles spatiales; aucun patron précis n'a été mis en évidence. Toutefois, la variation retrouvée d'une échelle spatiale à l'autre nous indique que cet aspect peut avoir une influence sur les résultats obtenus. Ainsi, certaines relations furent observées à toutes les échelles spatiales, mais d'autre seulement qu'à une seule. Il semble donc important, dans ce genre d'étude, de tenir compte de l'échelle spatiale utilisée ou bien idéalement de continuer à en utiliser plusieurs.

Parmi les retombées du projet, on note en premier lieu la l'obtention des premières données quantitatives sur l'occurrence de chacune des espèces dans les régions étudiées. De plus, comme nous obtenons des informations sur la répartition des chauves-souris le long du circuit, il est dorénavant plus facile de prévoir la présence d'une espèce. Ceci peut s'avérer utile dans le cadre d'autres projets touchant l'écologie ou la conservation des chauves-souris. Toutefois, le développement d'une méthode adéquate pour l'étude de la relation habitat/chauves-souris représente la retombée la plus importante du projet puisque celle-ci pourra éventuellement être appliquée à d'autres régions et répétée au fil des années. Il sera ainsi possible de percevoir les changements dans l'utilisation de l'habitat par les chauves-souris d'une région à l'autre, d'une année à l'autre, ou encore lors de perturbations naturelles ou de transformations dues au développement (ex. déforestation, urbanisation, etc.).

Afin d'obtenir une plus grande efficacité dans la caractérisation de l'habitat d'alimentation et de déplacements des chauves-souris, deux points, en particulier, pourraient être améliorés dans la méthode. Tout d'abord, un raffinement des variables d'habitat permettrait une analyse plus précise. Ainsi, les milieux boisés pourraient être définis comme composes de feuillus ou de conifères, de jeunes peuplements ou de peuplements matures. Les milieux ouverts pourraient aussi être catégorisés : un parc, un stationnement, une clairière, un champ agricole, un type de culture (ex. maïs, soja) etc. Cela permettrait peut-être une analyse plus fine. Également, la méthode nécessite davantage d'inventaires (nombre d'années d'étude) pour grossir l'échantillon des cris enregistrés. Ainsi, cela pourrait permettre, d'une part, de pouvoir faire des analyses avec les espèces moins fréquentes et d'autre part, on obtiendrait des résultats plus certains et avec une moins grande variance. On observe cet effet avec les données de Laval, qui comprennent 4 ans d'échantillonnage vs 2 ans pour les autres régions. En effet, la région de Laval, où le plus grand nombre de données de cris a peut-être permis de détecter un plus grand nombre de relations chauves-souris/habitats significatives.

Puisqu'ils représentent les premiers travaux sur la distribution des chauves-souris au Québec, le réseau québécois d'inventaires acoustiques de chauves-souris, et notre projet de caractérisation de l'habitat, en particulier, ouvrent la voie à plusieurs autres études sur les chiroptères. Parmi les avenues qui semblent les plus intéressantes pour compléter la présente étude, la localisation des sites de repos diurnes et des gîtes de maternité serait à privilégier. Cet aspect de l'écologie des chauves-souris pourrait avoir un impact sur la distribution des individus dans le paysage. En intégrant ces données aux cartes, il serait possible de mieux comprendre l'influence du lieu de gîte sur le lieu d'alimentation. Comme le réseau s'étend maintenant à 15 régions différentes, il sera éventuellement possible de répliquer le protocole dans deux régions forestières, par exemple, afin d'accroître et de préciser les connaissances acquises sur le circuit de la Mauricie.

Finalement, un autre aspect à surveiller à l'aide du réseau serait la progression des populations de certaines espèces de chauves-souris, particulièrement la grande chauve-souris brune (*E. fuscus)*, dans les centres urbains. En effet, notre étude laisse entrevoir que les milieux urbains ont une composition en espèces différente de celles des autres types de régions, tout en laissant de la place à certaines espèces qu'on aurait pû croire absentes de ces milieux. On pourrait aussi observer comment la composition en espèces change avec l'augmentation du développement urbain ou comment certaines pratiques dans l'aménagement du territoire (coupe d'arbres isolés ou de boisés, développement résidentiel, construction de routes, etc.) influencent la présence des espèces.

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